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Deliverable 1.2
Description of metrics and methodology used for assessment of KPI achievements and impact

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1. Executive Summary

This document shows how FA1-MOTIONAL is addressing the Key Performance Indicators stated in the Multi Annual Workplan of the EU-Rail Work programme, the Performance Indicators to be fulfilled within the project and the Impact the technical developments will have on a variety of topics of our lives.
The Key Performance Indicators (KPIs) represent the overall goals of the work programme and are to be reached by 2031. A credible pathway towards these goals is to provide and implement Performance indicators (PIs), which are related to the overall goals, but to be reached at the end of the FA1-MOTIONAL project by 2026.
To measure the KPIs and PIs, we defined a baseline for 2022 whenever possible and relevant by using e.g., reports on rail statistics (e.g., EUROSTAT [1], PRIME [2]), this baseline will later be used to measure the progress of our planned technical developments. Some of our KPIs and PIs do not require a baseline but have rather absolute goals to be reached.
Additionally, a clear methodology was defined, this information is needed to make the results comparable and repeatable. We selected different approaches for measuring the progress towards KPIs, PIs for our Technical Enablers and PIs for our Digital Enablers, due to their different nature of objectives. KPIs will be measured using demonstrations, simulations or expert judgement, based on the data availability and overall timeline of demonstrations stated in the EU-Rail Multi- Annual Workplan [3]. PIs for our technical enablers and digital enablers will be measured by comparing the current Technology Readiness Level to the target level stated in the Grant Agreement [27].
Our project and the successful implementation of technical and digital enablers will have a measurable impact on society and economics. We plan to quantitively assess these impacts based on all developments done in MOTIONAL. Other impacts (e.g., environmental, technological, political) will only be qualitatively assessed. The level of complexity of the developments and the numerous interdependencies within the rail system and the real world make it impossible to calculate the impacts precisely or map certain technical enablers directly to a specific impact. The results of the project can only be evaluated in a holistic approach and taken as estimation.
We conclude that the selected methods and approaches are the best way forward to fulfil the objectives of our project. This document will provide the baseline of all future work concerning KPIs within MOTIONAL and also Flagship Area 1.

2. Abbreviations and acronyms

Abbreviation / Acronym	Description
ATO	Automatic Train Operation
AWP	Annual Workplan
B2B	Business-to-Business
C-DAS	Connected Driver Advisory System
CEN	European Committee for Standardization
ERA	European Union Agency for Railways
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Units
FPM	Flagship project manager
GA	Grant Agreement
IDS	International Data Space
KPI	Key Performance Indicator
MAWP	Multi Annual Work Plan
MEP	Members of European Parliament
PI	Performance Indicator
PMO	Project Management Office
PRM	Person with Reduced Mobility
RDF	Resource Description Framework
S2R	Shift2Rail
SG	Subgroup
TE	Technical Enabler
TMS	Traffic Management Systems
TMT	Technical Management Meeting
TRL	Technology Readiness Level
TSR	Temporary Speed Restriction
TT	Transversal Topics
UC	Use Case
UWB	Ultra-Wide Band
WP	Work Package
WS	Work Stream

3. Background

The present document constitutes the Deliverable 1.2 "Description of metrics and methodology used for assessment of KPI achievements and impact" in the framework of the Flagship Project 1-MOTIONAL and the EU-RAIL MAWP [3]. KPIs listed in the MAWP, as well as Performance Indicators (PIs) from the Grant Agreement (GA [27]) are taken into account to create this document. Furthermore, it is the first version of a number of KPI documents prepared within the project and will provide input to the next Deliverables. Ongoing technical developments and ERJU communication will influence the results of the following deliverables (Figure 1).

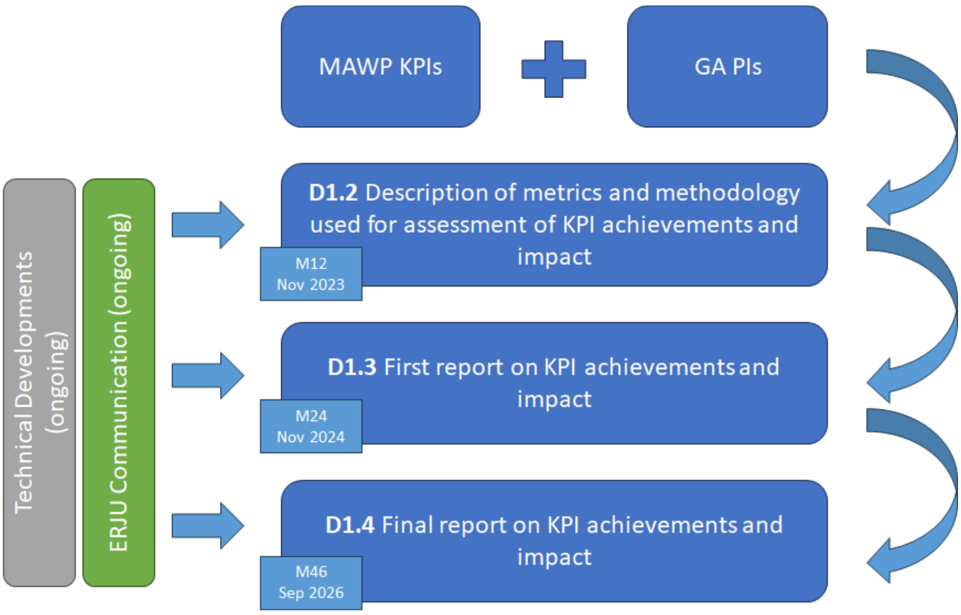

Figure 1: Structure of planned deliverables regarding KPI

We took KPI definitions from Shift2Rail into account in the initial definition of the KPI for FP1-MOTIONAL. The KPIs for Shif2Rail are collective KPIs for the entire program, while the ones for MOTIONAL are defined in the MAWP for the related Flagship Area.

The results from the Shift2Rail Cross-Cutting Activities (CCA) Projects IMPACT-1 [4] and IMPACT-2 [8] have been carefully analysed. The following conclusions were taken:

- For WS1 on rail traffic management the related KPI definitions from IMPACT-1 [5-7] and the related values from IMPACT-2 [9] were analysed, as well as the related IP2 sub-level KPI definitions and values. The related input coming from Shift2Rail TD2.9 is defined on a more extensive scope than the KPI defined for FP1-MONTIONAL. Consequently, qualitative inputs, methodology and approach were taken as background, but at the level required in WS1 a more detailed definition was needed and related baseline values need to be acquired.
- For WS2 on digital enablers the relation to the KPI from IMPACT-1 [4] and IMPACT-2 [8] turned out to be too indirect and more of qualitative nature, so that the input has been analysed but understood as not applicable. A shorter check has been done on the KPI from PRIME [2]. The definitions turned out to be helpful on the more detailed definition of the KPIs and PIs, as well as available values that can be used in the future.

4. Objective/Aim

This document aims to provide a comprehensive overview of the metrics and methodology used for the assessment of KPI achievements and impact in our research project deliverable. Our objective is to establish a credible pathway to technical KPIs through performance indicators, map KPIs, PIs, and demo cases, assess KPIs, and measure their contribution to impacts set in the MAWP.

The KPI and PI definition process is a critical step in our research project as it enables us to establish clear and measurable objectives for performance evaluation and to ensure that our project is on track to achieve its goals. By defining KPIs and PIs, we can establish a baseline for performance measurement and track progress over time. The definition of metrics to measure these indicators is equally important as it ensures that our performance evaluation is objective and quantifiable, allowing us to make data-driven decisions that will ultimately improve our project's outcomes. Through this process, we can identify areas for improvement and optimize our resources, ultimately leading to more efficient and effective project outcomes.

The MOTIONAL consortium has established an internal process to achieve this objective. We established a KPI Task Force within MOTIONAL that consists of System Experts from WS1 and WS2, our Technical Coordinator, both Flagship Project Managers, KPI Experts in the Consortium, and our Project Management Office (PMO). This Task Force contributed with their experience and lessons learned from previous Shift2Rail projects (e.g., IMPACT-1 [4], IMPACT-2 [8], MaaSive [10], COHESIVE [11], X2Rail-2 [12], X2Rail-4 [13]) to improve the KPI process of MOTIONAL. This group meets on a weekly basis (frequency adjusted based on need) to discuss KPI topics and create a roadmap for handling and implementing requests from the ERJU.

This document provides:

- the structure of technical KPIs and a credible pathway to reach these KPIs (Chapter 5)
- An initial assessment based on available specifications for technical solutions (Chapter 6)
- Methodology and metrics on how to calculate the contribution of the project developments to the technical KPIs (Chapter 7)
- The contribution to Impacts (Chapter 8)
- Annex 1 - Technical and Digital Enablers of FA1-MOTIONAL
- Annex 2 - Mapping of KPIs and PIs

5. Structure of technical Key Performance Indicators

5.1. Credible Pathway to KPIs through Performance Indicators

Within the AWP 2022-2024 [10] there are no specific impacts listed to be reached in 2025 for WS1. Instead, the project is required to set out a credible pathway (Figure 2) to contribute to the demonstration and monitoring of the listed innovative solutions to achieve certain KPIs in 2031 as listed in the EU-RAIL Multi-Annual Work Programme [3]. For MOTIONAL specific Performance Indicators (PIs) were created for WS1 and WS2 to be reached at the end of the project in 2026, taking the planned TRL of the technical enablers (Annex 1 – Technical and Digital Enablers of FA1-MOTIONAL) into account, as well as the KPIs of the EU-RAIL Multi-Annual Work Programme [3](Table 1).

Table 1: KPI and PI definition and explanation

Abb	Name	Description	Documented in	Deadline
KPI	Key Performance Indicator	Large scale goals potentially covering multiple Enablers and projects in FA1.	MAWP	2031
PI	Performance Indicator	Measurable goals for the 17 project objectives and related to overall KPIs.	FA1-MOTIONAL GA	2026

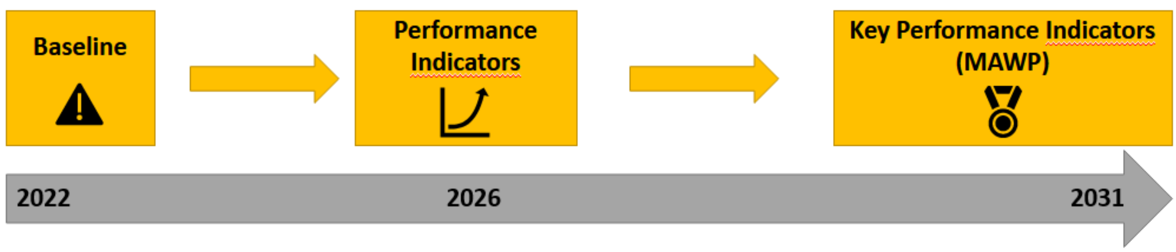

Figure 2: Pathway to KPIs of the EU-Rail Multi-Annual Work Programme

5.2. Mapping of KPIs, PIs and Demo Cases

For MOTIONAL WS1 we established the structure shown in Figure 3. On the top and most general level we have the KPIs listed in the MAWP [3]. Below we have the Performance Indicators on the Project level and listed in the current Grant Agreement [27]. Followed by the Demonstration Cases on Work Package Level. Note that muliple Demo Cases could feed into a Performance Indicator. This level is monitored on a monthly bases within our regular TMT meetings. The Demo Cases consist of one or multiple Use Cases that are handled within the Work Packages. This approach allows us to monitor the technical developments and ultimately the progress towards our planned demonstrations, while at the same time monitoring the progress towards the Performance indicators of the Project.

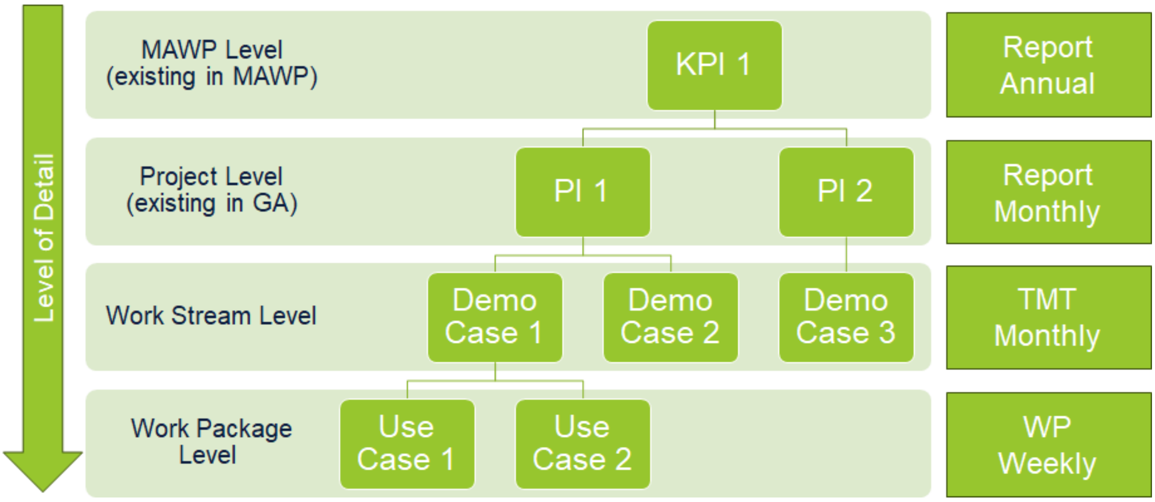

Figure 3: Structure of KPIs for MOTIONAL for WS1

The mapping of Demo Cases towards the PIs and KPIs was done for MOTIONAL. It is being tracked on ProjectPlace in an Excel File and updated on a regular basis. For further information see Annex 2. This approach is valid for WS1.1 and WS1.2. WS1.3 mapped the Performance Indicators to Development Use Cases that will be implemented and tested by the end of 2024.This approach is aligned with the structure of the WPs in our Grant Agreement [27].

The approach for WS2 differs to accommodate the PIs for the Digital Enablers (Figure 4). There are no demonstrations planned and the methodology to measure the PIs is established in Chapter 7. For WS2 we create scenarios that can be linked to the Performance Indicators, as there are no Demonstrations planned.

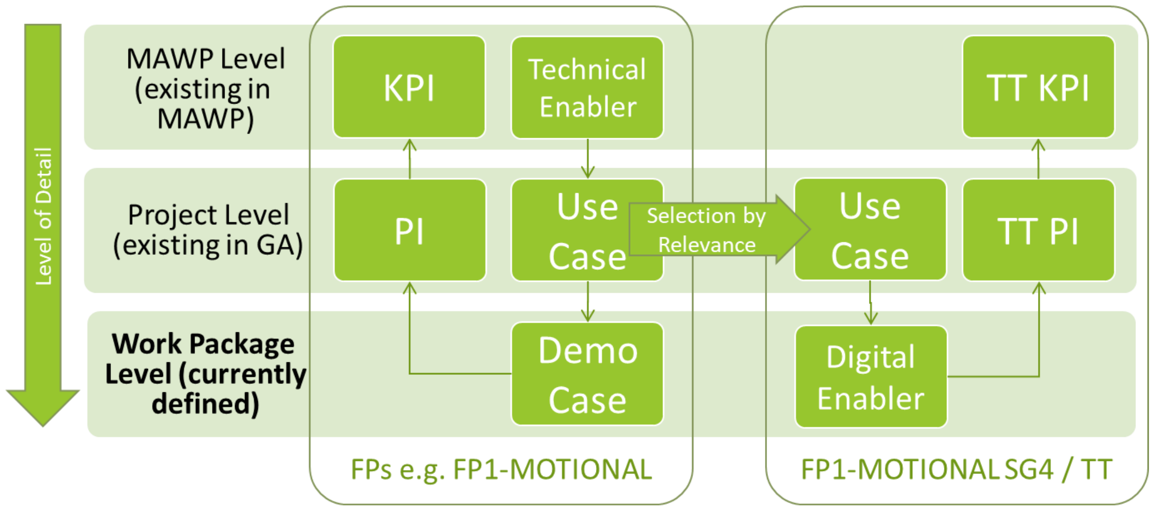

Figure 4: Structure of KPIs for FP1-MOTIONAL for WS2 in relation to the other FPs

Digital enablers in the WS2 of MOTIONAL constitute a transversal topic for all the Flagship Projects. Those will most likely have no direct improvements for the end users (e.g., passengers, customers, businesses) but lead to a major improvement inside the railway business for the digital collaboration e.g., between suppliers for traffic management systems and railway infrastructure managers. The exchange and validation process will become quicker, more reliable and detailed and – most important more effective. For this purpose, we select suitable use cases, which will be used to demonstrate that the TT-related PIs and KPIs are improving, as well as indirectly the business-related PIs and KPIs in the Flagship Projects including the WS1 of FP1-MOTIONAL.

6. Assessment of KPIs and PIs

This chapter provides an overview of the MAWP KPIs, the methodology how to obtain them and information about the progress tracking. Additionally, we provide an overview about the project PIs, their baseline and the current development status.

6.1. MAWP - KPI Baseline

The following table contains the KPIs for FA1 and TT of the MAWP [3], the Baseline 2022 and the progress recorded. The blue fields show additions during MOTIONAL, the remaining table shows the MAWP document [3].

The general baseline for WS1 is the year 2022 with respect to operational performance indicators as well as parameters of technology implemented in the field. Technology available on the market, but not applied on operational lines, will not be considered as baseline. Especially operational data may be critical to be collected as developments are ongoing at the related railways to improve critical parts of the networks or nodes and hence are subject to significant changes. Consequently, available data of later or earlier years will be used depending on their availability and coherency with the other values and PIs.

The “transversal” digital enablers developed by MOTIONAL WS2 are an innovation in the Rail System introduced for the first time as a generalized capability shared by all its stakeholders. Consequently, an established “baseline” for comparison does not exist for these enablers within the Rail System. A set of tests and measurements based on best practices in other sectors, or the technical-scientific literature will be performed by the project to establish a baseline, against which to assess quantifiable progress in further development phases and successor projects in the EU-Rail programme.

The progress in reaching the MAWP KPIs can be obtained using three different methods. All have certain advantages and disadvantages (Table 2).

Table 2: Explanation of three methods of validation: Demonstration, Simulation, Expert Judgement

Type of Validation	Description	Advantage	Disadvantage
Demonstration	Demonstration in relevant or operational environment (TRL>5). Demonstrations will be set up by partners to validate specific technical developments that contribute to the overall KPIs.	High TRL to be reached; testing of new and improved technologies in the field; high trustability of results	Time consuming; high cost; high effort
Simulation	Simulations are representing systems and/or processes from the real world in a model and calculate their dynamic behaviour. The models represent the relevant part of the real systems and processes while leaving out the not relevant properties. To ensure that a simulation provides useful output it is important to use suitable models, which are reflecting the right properties of the reality.	Transparent approach, which can be validated; ess effort than real test; Many tools and algorithms available; e.g., optimization algorithms	More effort than expert estimations; Effort for data acquisition; Needs one specific real example, which leads to additional effort for generalization
Expert Judgement	Experts are asked to evaluate certain KPIs based on their experience and knowledge in the field, they provide a written evaluation of the status of KPIs. Experts are partners within MOTIONAL, as they need to have knowledge of the use cases and technical improvements. The evaluation will be reviewed by a team to check argumentation and challenge it if necessary.	Fastest Approach with very low effort; Quick to be adopted to changed conditions; Applicable at unknown or fuzzy conditions; Potentially low effort for generalization	Potentially unprecise up to massively biased; Difficult to be validated or proved (as implicit conditions are unknown or biased)

Table 3: Baseline and Method of Validation established within MOTIONAL (blue) and KPIs of the MAWP for WS1 and WS2

#	MAWP KPI	Baseline 2022	Method of Validation
WS1.1			
1.1	Increased number of possible trains on a given infrastructure on a reference day using improved processes and methods. Demonstrators SG1 and SG2 contributes to an expected increase 5% to 20%, depending on the line or area.	For relevant demonstrators in WS1.1 and WS1.2, based on recorded standard-scenarios in real-world, a comparison of additional numbers of possible standard paths 'before and after' is performed.	By reporting results of initial tests and evaluations based on the planned improvements by expert judgement
1.2	Reduction of answering time between the short-term request of a cross-border train path and the answer with a firm offer. Down to 5 minutes	Reduction of answering time down to 5 minutes based on the assumption that the quality of the train path would be the same. Focus is only the answering time itself and not the utilization of the results.	By reporting results of initial tests and evaluations based on the planned improvements by expert judgement
1.3	Improved robustness of timetables and hence, reduced impact of disturbances and Disruptions. Demonstrators SG1 contributes to an expected decrease 5% to 15% of delay minutes in a reference week depending on the line or area.	For relevant demonstrators in WS1.1 processing the historical data and implement the delay distribution into RailSys for stochastic models will contribute.	By reporting results of initial tests and evaluations based on the planned improvements by **expert judgement**
WS1.2			
2.1	Prediction Quality: less than 5 percent of trains more than 5 minutes mean deviation in a typical scenario of at least 100 trains running in a 2h interval ahead of actual time	For relevant demonstrators in WS1.2, based on recorded standard-scenarios in real-world, a comparison of forecast calculation results with the final real-operation is	By reporting results of initial tests and evaluations based on the planned improvements by **expert judgement**

		performed.	
2.2	Prediction performance (incl. Dynamic infrastructure restriction handling, train regulation and automated conflict resolution): less than 120 secs in a typical scenario of at least 100 trains running in a 2h interval ahead of actual time	For relevant demonstrators in WS1.2, based on standard-scenarios in real-world, the duration of forecast calculation is measured.	By reporting results of initial tests and evaluations based on the planned improvements by **expert judgement**
2.3	ATO Journey Profile provision cycle time down to 30 secs	For relevant demonstrators in WS1.2, based on standard-scenarios in real-world, the provision cycle time of Journey Profiles generated by the TMS is measured.	By reporting results of initial tests and evaluations based on the planned improvements by **expert judgement**
WS1.3			
3.1	Demand forecast for improved service planning: o Achieve 65% precision in the average forecast 1 week in advance o Achieve 80% precision in the forecast at 1 hour	Currently, a multimodal demand predictive model based on real-time data is not in production (deployed and operational). For that reason, we do not have KPI metrics for the base case. This type of model is planned to be developed in this project which means that in the future there will be metrics to verify compliance with the KPIs	Based on test results evaluating the forecast precision based on **simulated** or test service data.
3.2	Improved matching between demand and supply: o Achieve 75% reaching planned travel time of passengers	Currently, a multimodal demand predictive model based on real-time data is not in production (deployed and operational). For that reason, we do not have KPI metrics for	Will be based on the result of **simulations** and analysis of the impact of processing solutions put in place.

		the base case. This type of model is planned to be developed in this project which means that in the future there will be metrics to verify compliance with the KPIs	
WS2 – Digital Twin Capability			
4.1	Number of infrastructure inspections that can be conducted in laboratory without requiring field inspection	Establishing a baseline within MOTIONAL	**Simulation**
4.2	Number of rolling stock inspections that can be conducted in laboratory without requiring field inspection.	Establishing a baseline within MOTIONAL	**Simulation**
4.3	Number of virtual certification tasks that can be conducted in a laboratory	Establishing a baseline within MOTIONAL	**Simulation**
4.4	Number of predicted future behaviours thanks to the digital twin use	Establishing a baseline within MOTIONAL	**Simulation**
WS2 – Data modelling			
4.5	Reduction of times the same data type is managed in isolated manner in a process using an independent system.	Establishing a baseline within MOTIONAL	**Simulation**
4.6	Number or shared data entities that have been harmonized	Establishing a baseline within MOTIONAL	**Simulation**
WS2 – Data Quality			
4.7	% of coverage physical asset with related digital twins (completeness)	Establishing a baseline within MOTIONAL	**Simulation**
4.8	% of errors present in the digital twins list (inconsistency)	Establishing a baseline within MOTIONAL	**Simulation**
WS2 – Cyber Security			
4.9	Data Security – Role based security of data in DT environment measured by passing of tests designed and administered by ethical (“white hat”) hackers (hack tests)	Establishing a baseline within MOTIONAL	**Simulation**
4.10	Time to respond and resolve a vulnerability	Establishing a baseline within MOTIONAL	**Simulation**
WS2 – Connectivity			
4.11	Time to complete a data transfer task from the Data Provider to the Data Consumer	Establishing a baseline within MOTIONAL	**Simulation**

6.2. MOTIONAL - PI Baseline

The following table contains the Performance Indicators and their Baseline for the MOTIONAL project (GA [27] Table 11&12). In the blue fields the new information regarding the progress recorded is shown (Table 4).

The progress of the PIs is recorded by comparing the target TRL to the current TRL of development. TRL definition is based on Horizon 2020 – Work Programme 2014-2015 [15].

- TRL1: basic principles observed
- TRL2: technology concept formulated
- TRL3: Specifications or proof of concept
- TRL4: Technology or component validated in lab
- TRL5: Technology validation in relevant environment
- TRL6: Technology demonstration in relevant environment
- TRL7: System Prototype demonstration in operational environment
- TRL8: System complete and qualified incl. Testing and demonstration
- TRL9: System proven in operational environment

Table 4: Baseline and Progress recorded of the PIs for WS1 and WS2

#	Performance Indicators for MOTIONAL	Baseline	Progress Recorded using Current TRL vs Target TRL
PI1	Number of solutions developed: 3 Number of solutions implemented: 1	Number of integrated solutions implemented today is none (0). Number of integrated cross-border dispatching solution is none (0). Concept from S2R (Fr8Rail III) [16] for integrated yard and network interaction. Test evaluated for Malmö node in simulation environment. Today dispatchers have several information sources and systems, there is a need of integration.	TRL3 vs TRL6
PI2	Number of optimised timetable solutions: 3 Number of solutions implemented: 1	Number of integrated solutions implemented today is none (0) Some solutions for optimised timetable implemented at local basis	TRL3 vs TRL6-7
PI4	Number of integrated information interfaces that will contribute to a harmonised cross-border traffic management supported by the future European TMS: 2	Number of integrated information interfaces for Cross border traffic, none (0)	TRL3 vs TRL6-7

PI3	Number of successful feedback loops solutions put in place between operations and planning: 2 Number of developed methods for TMS – C-DAS/ATO: 2	Different solutions and levels for feedback loops implemented today	TRL3 vs TRL6-7
PI5	Number of multi-actor planning and decision support system solutions for incidents and disruptions with human-in-the-loop recognition in place: 2	Different solutions and levels for incidents and disruptions management are implemented today	TRL3 vs TRL8
PI7	Computing time to produce a feasible (= conflict-free) plan i.e., a route and a schedule for each train, with a set of 100 trains running in a 2h interval ahead of actual time, running at most 60 seconds.	Different solutions and levels for solving timetable conflicts are implemented today but mostly with very limited scope and reaction times > 1min; none (0) are used in production.	TRL3 vs TRL5
PI6	Number of TMS - ATO/C-DAS modules tested and assured individually ready to build up complexity step-by-step: 3	TMS-side is less developed. TMS-C-DAS/ATO is under a current evolution and transition. A few ATO-lines in operation	TRL3 vs TRL5-7
PI10	Calculation of the short-term demand prediction is feasible There is a distribution of predicted demand by hour There is detection of deviations not contemplated in baseline	There is no available distribution per hours for a predicted demand Currently there is no mechanism for the detection of deviations	TRL3 vs TRL5-7 depending on the demonstration
PI8	Number of B2B services put in place >3	Only rudimentary approaches are present for B2B services	TRL3 vs TRL 6-8 depending on the demonstration
PI9	Impact on passenger flow and traveller satisfaction. Based on the demos survey: Impact on passenger flow > 25% Customer satisfaction when using the proposed inclusive services > 75%	Baseline related to demos context: existing solutions available at the station, digital assistance and automatic gates.	TRL3 vs TRL 6-8 depending on the demonstration
PI11	Number of implemented IDS connectors; mean of	none	TRL3 vs TRL6

	Verification: registered number of IDS connectors		
PI12	Number of users of IDS broker services; mean of Verification: registered number of users	none	TRL3 vs TRL6
PI16	Number of users of the digital assets engineer toolbox	30 (EULYNX [17], RCA [18])	TRL3 vs TRL6
PI14	Number of data models in the Common Domain Ontology/Conceptual Data Model	6 (ERA v 3.0.0 [21], EULYNX 9 mar 2023 [22], IFC v2021-02-01 [23], RSM v1.2 ext [24], TRANSMODEL v6.56 [25], X2RAIL-4 v2022-01-13 [26])	TRL3 vs TRL6
PI15	Number of users of the machine-readable, platform independent, abstract Rail System common domain ontology / conceptual data model	Baseline: 20 (OPTIMA [19], LINX4RAIL demonstration [20])	TRL3 vs TRL6
PI13	Number of users of IDS AppStore; mean of Verification: registered number of users	none	TRL3 vs TRL6
PI17	2 Digital Twins supported by the Digital Twin support, development and run-time environment	none	TRL3 vs TRL6

7. Methodology

In this section we describe the Metric and Methodology for all KPIs and PIs of MOTIONAL. Both are needed to calculate / estimate the contribution of the project developments to the technical KPIs and ultimately the contribution to impacts set in the MAWP [3]. It is important to mention that the calculation is based on the quality of data available, which will differ for every KPI and PI, but also over the next decade.

The metric is defining the system of measurement. The Methodology clearly describes how the KPI/PI is measured, including a specific order of actions to obtain the results. This defined approach will allow for a reproduction of the results and better comparability over time.

7.1. WS1.1 KPIs

KPI #1.1	Increased number of possible trains on a given infrastructure on a reference day using improved processes and methods: Baseline 2022, expected increase 5% to 20%, depending on the line or area.
Metric	Based on standard-scenarios on a given infrastructure and reference day. Comparison of real-operation with demonstrated solution results.

Methodology	For relevant demonstrators: 1. Select a number of standard real-world operational scenarios. 2. For all scenarios, run forecast calculation for a representative set of trains at given infrastructure and reference day. Compare results with the amount of trains in real operations. 3. Measure the mean result accordingly. Check whether the resulting mean value is increased between 5% to 15% possible train to run. Note: This methodology can only be applied once demonstrators for calculation are available in the project.

KPI #1.2	Reduction of answering time between the short-term request of a cross-border train path and the answer with an adequate offer: Down to 5 minutes
Metric	Based on standard-scenarios and comparison of expected answering time results with same quality of the train path in real-operation. Focus is the answering time itself and not the utilization of the results
Methodology	For relevant demonstrators: 1. Select a number of standard real-world operational scenarios. 2. For all scenarios, run forecast calculation for a representative set of 100 trains at different stages and compare results with the answering time in real operations. 3. Measure the mean result accordingly. Check whether the resulting mean value is down to 5 min. Note: This methodology can only be applied once demonstrators for calculation are available in the project.

KPI #1.3	Improved robustness of timetables and hence, reduced impact of disturbances and disruptions: Baseline 2022, expected decrease 5% to 15% of delay minutes in a reference week depending on the line or area
Metric	Based on standard-scenarios and comparison of expected disturbances and disruptions in final real-operation. Comparison of real-operation with demonstrated solution results.
Methodology	For relevant demonstrators: 1. Select a number of standard real-world operational scenarios 2. For all scenarios, run forecast calculation/demonstration of solution and estimate the mean value for delay minutes. 3. Check whether the resulting mean value is decreased between 5% to 15% Note: This methodology can only be applied once demonstrators for calculation are available in the project.

7.2. WS1.2 KPIs

KPI #2.1	Prediction Quality as the basis for decision quality in Traffic Management: For a representative set of 100 trains running in a 2h interval ahead of actual time, less than 5 percent of the predicted timing shall not deviate from the actual more than 5 minutes. Note: Train cancellations not considered
Metric	Based on recorded standard-scenarios, comparison of forecast calculation results with final real-operation.
Methodology	For relevant demonstrators: 1. Select a number of standard real-world operational scenarios including train tracking information. 2. For all scenarios, run forecast calculation for a representative set of 100 trains at different stages and compare results at +2h with the related effective train positions included in the train tracking information from real-operation. 3. Measure the mean deviations accordingly. Note: This methodology can only be applied once first prototypes for an upgraded forecast calculation are available in the project.

KPI #2.2	Prediction performance as the basis for in-time decision making in Traffic Management: less than 120 seconds in a typical set of 100 trains running in a 2h interval ahead of actual time. Note: Prediction shall consider dynamic infrastructure constraints (e.g., TSR, track blockages), implemented train control decisions and automated conflict resolution
Metric	Based on standard-scenarios, measuring the duration of forecast calculation.
Methodology	For relevant demonstrators: 1. Select a number of standard real-world operational scenarios including TSR and track blockages and deviations from plan in a +2h horizon. 2. For all scenarios, run forecast calculation for a representative set of 100 trains for a +2h forecast and create the mean value for required running time in seconds. 3. Check whether the resulting mean value is less than 120 seconds. Note: This methodology can only be applied once first prototypes for an upgraded forecast calculation are available in the project.

KPI #2.3	ATO Journey Profile provision cycle time down to 30 secs
Metric	Based on standard-scenarios, measuring the provision cycle time of Journey Profiles generated by the TMS.
Methodology	For relevant demonstrators:

	1. Select a number of standard real-world operational scenarios including TSR and track blockages and deviations from plan in a +2h horizon. 2. For all scenarios, run forecast calculation for a representative set of 100 trains for a +2h forecast and generate ATO Journey Profiles for the trains being active in that time window. 3. Send the Journey profiles to a dedicated disk space for checking. 4. Check the last write access times of the sets of JPs created for each scenario to be less than 30 seconds. Note: This methodology can only be applied once first prototypes for an upgraded forecast calculation and JP provision are available in the project

7.3. WS1.3 KPIs

KPI #3.1	Achieve 50% precision in the average forecast 1 week in advance; Achieve 65% precision in the forecast at 1 hour.
Metric	Demand forecast precision
Methodology	1. Prepare the evaluation context (network, passenger demand evaluation solution) 2. Lauch the demand forecast solution at a given point of time and collect the result for the desired period. 3. Wait for the end of the period and measure the effective passenger demand (in case of simulation, time can be virtually accelerated) 4. Compare the forecasted demand to the effective demand and work-out the precision

KPI #3.2	Achieve 60% reaching planned travel time of passengers.
Metric	Improvement of the matching of demand with supply.
Methodology	1. Prepare the evaluation context (network, journeys to be evaluated, unplanned events including demand variation and disruptions) 2. Record planned travel times for journeys under evaluation 3. Start the evaluation period and make sure that unplanned events occur 4. Let the disruption management solution accommodate the unplanned events 5. Collect effective travel times for journeys under evaluation and evaluate gaps on travel times for journeys subject to unplanned events

7.4. WS2 KPIs

There are no demonstrators planned In WS2. The aim is to support WS1 and other FPs with digital enablers. Hence, the approach is to support the demonstration of the capabilities on selected scenarios and/or use cases.

KPI #4.1	Number of infrastructure inspections that can be conducted in laboratory without requiring field inspection. With the help of digital twins their degradation behaviour can be predicted. Track assets as the rails, frogs, tongues or switch motors can be modelled and the 100% threshold where a maintenance and/or replacement must be done can be predicted. If additional measurements are available from measurement trains the degradation model can be calibrated. The maintenance can be done on the prediction and closer to the 100% threshold.
Metric	Percentage of virtual infrastructure inspections over total
Methodology	1. Establish Number of total inspections done, based on Use Cases received in FP1-MOTIONAL 2. Select representative infrastructure elements from inspection Use Cases 3. Model selected infrastructure elements in Digital Twin development environment 4. Acquire instance data of selected infrastructure elements into Digital Twin runtime environment 5. If further measurement data is available: Use for calibration 6. Perform virtual inspection on Digital Twin of instantiated elements of the infrastructure 7. Calculate percentage of virtual vs total inspections

KPI #4.2	Number of rolling stock inspections that can be conducted in laboratory without requiring field inspection. With the help of digital twins the degradation of mechanical parts of the trains as e.g. wheels, brakes, springs, dampers, gear oils, etc and their degradation behaviour can be predicted. The 100% threshold where a maintenance and/or replacement must be done can be predicted. If additional measurements are available from measurement on the trains during earlier inspections the degradation model can be calibrated. The maintenance can be done on the prediction and closer to the 100% threshold.
Metric	Percentage of virtual rolling-stock inspections over total
Methodology	1. Establish Number of total inspections done, based on Use Cases received in MOTIONAL 2. Select representative rolling stock elements from inspection Use Cases 3. Model selected rolling stock elements in Digital Twin development environment

	4. Acquire instance data of selected rolling stock elements into Digital Twin runtime environment 5. If further measurement data is available: Use for calibration 6. Perform virtual inspection on Digital Twin of instantiated elements of the rolling stock 7. Calculate percentage of virtual vs total inspections

KPI #4.3	Number of virtual certification tasks that can be conducted in a laboratory. With digital twins and their behavioural models can be predicted how trains or tack assets are working. By using them to replace or complement tests by simulations the certification can be done virtually. E.g. crosswind sensibility of high-speed trains can be done by their digital twins instead of wind tunnel experiments.
Metric	Percentage of virtual certification in the lab over total
Methodology	1. Establish Number of total certifications done, based on Use Cases received in MOTIONAL 2. Select equipment/process for certification from Use Cases 3. Model selected equipment in Digital Twin development environment 4. Acquire instance data of selected equipment into Digital Twin run time environment 5. Execute certification Use Case using digital twin of selected equipment 6. Calculate percentage of virtual vs total certifications

KPI #4.4	Number of predicted future behaviours thanks to the digital twin use. With digital twins and their behavioural models can be predicted how trains or tack assets are changing their behaviour in the future or how new systems are working. By using them to replace or complement tests by simulations the certification can be done virtually.
Metric	Number of Digital Twin simulation/prediction runs
Methodology	1. Describe expected system behavior in Digital Twin development environment 2. Generate alternate scenarios (conditions) as data sets to be injected into Digital Twin runtime environment 3. Perform Digital Twin simulations under different alternate scenarios to predict behavior under different conditions

KPI #4.5	Reduction of number of times the same data type is managed in isolated manner in a process using an independent system. Data entities as e.g. timetables, type, age and position of track assets or type, length, braking

	performance and age of trains, are needed for several different purposes. Consequently, they are copied to the related data spaces. This leads to significant maintenance issues and/or inconsistencies between the data copies. The KPI measures how many of those copies can be removed and replaced by links to a single storage location.
Metric	Percentage of reuse of data types to represent the same entity in independent systems
Methodology	1. Identify common data entities used in multiple independent systems from Use Cases 2. Create a conceptual, system independent model of the common data entities in the Conceptual Data Model 3. Generate system-specific data types automatically from common Conceptual Data Model

KPI #4.6	Number or shared data entities that have been harmonized. Data entities as e.g. timetables, type, age and position of track assets or type, length, braking performance and age of trains are needed for several different purposes. Consequently, they are copied to the related data spaces. This leads to significant maintenance issues and/or inconsistencies between the data copies. The KPI measures how many of those copies can be removed and replaced by links to a single storage location.
Metric	Percentage of reuse of common conceptual data entities
Methodology	1. Identify common data entities from Use Cases 2. Merge or federate common data entity descriptions into a 'harmonized' conceptual model in the common Conceptual Data Model

KPI #4.7	% of coverage physical asset with related digital twins (completeness)
Metric	Percentage of assets digital twins over total assets
Methodology	1. Establish Number of total assets, based on Use Cases received in FP1-MOTIONAL 2. select infrastructure and rolling stock assets from Use Cases 3. Model selected assets into Digital Twin development environment (see KPI #4.1 and #4.2) 4. Compute number of created Digital Twins over total 5. Calculate percentage of virtual vs total assets

KPI #4.8	% of errors present in the digital twins list (inconsistency)
Metric	Digital Twin runs that end in error over total runs
Methodology	1. Establish Number of total runs, based on Use Cases received in FP1-MOTIONAL 2. Create composite Digital Twins using Functional Mock-up Interface (FMI) industry standard

	3. Create test data sets for multiple alternate scenarios 4. Perform multiple composite Digital Twin runs under test data sets 5. Create Digital Twin test runs logs and reports 6. Calculate percentage of virtual vs total runs

KPI #4.9	Data Security – Role based security of data in DT environment measured by passing of tests designed and administered by ethical ("white hat") hackers (hack tests). E.g. penetration tests on data exchange can be done by hackers to get the time until the communication link is corrupted.
Metric	Number of security provisions breaches
Methodology	This measurement will be adopted as a baseline of the system set up within FP1-MOTIONAL. The same methodology will be used to measure improvements in future projects. 1. Design and Create security breach campaign (hack tests) for federated data space based on Use Cases 2. Execute hack tests campaign 3. Generate security traces, logs and reports

KPI #4.10	Time to respond and resolve a vulnerability
Metric	Hours/minutes/seconds
Methodology	This measurement will be adopted as a baseline of the system set up within FP1-MOTIONAL. The same methodology will be used to measure improvements in future projects. 1. Design and Create vulnerability tests, e.g., intentionally remove selected security provisions in test environment 2. Perform hack test (see KPI #4.9) 3. Measure time to discover and resolve security breach

KPI #4.11	Time to complete a data transfer task from the Edge to the Cloud.
Metric	Hours/minutes/seconds
Methodology	This measurement will be adopted as a baseline of the system set up within FP1- MOTIONAL. The same methodology will be used to measure improvements in future projects. 1. Design and create test campaign 2. Perform federated data space data transfer campaign for a. Infrequent asynchronous large data sets transfer b. Frequent synchronous small data sets transfer c. Near-real-time data streaming transfers 3. Generate data transfer traces, logs and reports

7.5. PIs MOTIONAL

PI1	Number of solutions developed: 3 Number of solutions implemented: 1
WP	4, 5, 11, 12
Metric	Number of solutions developed, number of solutions implemented in the respective work packages
Methodology	Analysis of development and demonstration reports and list of the solutions put in place

PI2	Number of optimised timetable solutions: 3 Number of solutions implemented: 1
WP	6, 7, 8, 9
Metric	Number of modules developed, number of solutions implemented in the respective work packages
Methodology	Analysis of development and demonstration reports and list of the modules put in place

PI3	Number of successful feedback loops solutions put in place between operations and planning: 2 Number of developed methods for TMS – C-DAS/ATO: 2
WP	8, 9
Metric	Number of modules developed, number of solutions implemented in the respective work packages
Methodology	Analysis of development and demonstration reports and list of the modules put in place

PI4	Number of integrated information interfaces that will contribute to a harmonised cross-border traffic management supported by the future European TMS: 2
WP	4, 5, 11, 12
Metric	Number of integrated interfaces for cross-border traffic management in the respective work packages
Methodology	Analysis of development and demonstration reports and list of the solutions with related demonstrations put in place

PI5	Number of multi-actor planning and decision support system solutions for incidents and disruptions with human-in-the-loop recognition in place: 2
WP	13, 14
Metric	Number of multi-actor planning and decision support system solutions implemented in the respective work packages
Methodology	Analysis of development and demonstration reports and list of the solutions put in place

PI6	Number of TMS - ATO/C-DAS modules tested and assured individually ready to build up complexity step-by-step: 3

WP	8, 9, 15, 16
Metric	Number of TMS - ATO/C-DAS modules tested and assured individually ready to build up complexity step-by-step
Methodology	Analysis of development and demonstration reports and list of the modules put in place

PI7	Computing time to produce a feasible (= conflict-free) plan i.e., a route and a schedule for each train, with a set of 100 trains running in a 2h interval ahead of actual time, running at most 60 seconds.
WP	17, 18
Metric	Computing time measurement result less or equal 60 seconds
Methodology	• Set-up of 5 test scenarios for all relevant demonstrators involving hundred trains and a 2h forecast; • For each scenario, calculate the forecast followed by conflict detection/resolution; • Measure computing times involved and check to be less or equal 60 seconds;

PI8	Number of B2B services put in place >3
WP	20, 21
Metric	Number of services implemented
Methodology	Analysis of development reports and list of B2B services put in place

PI9	Impact on passenger flow and traveller satisfaction. Based on the demos survey: Impact on passenger flow > 25% Customer satisfaction when using the proposed inclusive services > 75%
WP	22, 23
Metric	Statistics based on demo survey
Methodology	Demonstration scenarios include the evaluation of the PI 1. For passenger flow this is based on the time to go through mobility hubs and switch between modes using the solutions put in place by motional 2. For satisfaction this is based on tester feedback

PI10	Calculation of the short-term demand prediction is feasible There is a distribution of predicted demand by hour There is detection of deviations not contemplated in baseline
WP	24, 25
Metric	Estimation of precision of demand forecast
Methodology	Similar to the one used in KPI 3.1

PI11	Number of implemented IDS connectors; mean of Verification: registered number of IDS connectors
WP	31
Metric	Number of entries in Federated Data Space connector's catalog
Methodology	Generated automatically by Dataspace's registry

PI12	Number of users of IDS broker services; mean of Verification: registered number of users
WP	31
Metric	Number of users in Federated Data Space catalog
Methodology	Generated automatically by Dataspace's registry

PI13	Number of users of IDS AppStore; mean of Verification: registered number of users
WP	31
Metric	Number of users in Federated Data Space catalog
Methodology	Generated automatically by Dataspace's registry

PI14	Number of data models in the Common Domain Ontology/Conceptual Data Model
WP	30
Metric	Number of RDF graphs
Methodology	Generated automatically by Common Domain Model graph database repository

PI15	Number of users of the machine-readable, platform independent, abstract Rail System common domain ontology / conceptual data model
WP	30
Metric	Registered user accounts in Common Domain Model graph database repository
Methodology	Generated automatically by Common Domain Model graph database repository

PI16	Number of users of the digital assets engineering toolbox
WP	27
Metric	Registered user accounts in digital assets engineering toolbox software
Methodology	Generated automatically by digital assets engineering toolbox software

PI17	Number of Digital Twins supported by the Digital Twin support, development and run-time environment
WP	28, 29
Metric	Number of FMU
Methodology	Digital Twins are developed according to the Functional Mock-up Interface standard specification and consist of self-contained, compiled "Functional Mock-up Units" (FMU). These are created using the Digital Twin support

	and development environment and executed in the Digital Twin run-time environment. The number of such distinct FMUs developed and deployed is therefore the value of this performance indicator.

8. Contribution to Impacts

The technical developments within MOTIONAL will impact a variety of fields of our lives. Figure 5 shows the types of impact we are foreseeing based on our planned activities. Our project PIs can be mapped quantitatively to the Economic and Societal Impacts, which makes an assessment possible (shown in dark green in Figure 5). All remaining impacts can be assessed qualitatively (shown in light green in Figure 5).

Figure 5: Impact Categories for MOTIONAL

Conceptually the two KPIs for economic and societal impact can be quantified by modelling the impact on the railway's operation and the resulting journey quality of the passengers. So, in simple terms the before and after can be compared in a simulation and the positive effect can be rated in terms of money, e.g., saved by avoiding delays or missed connections. Generally, the dimension of the impact depends on the priority and coverage of the deployment of the developed solutions. To get the impact optimally quantified, a consequent full roll-out with priority is assumed.

The qualitative impacts are explained in the following sections from 8.3 to 8.7. They can be described and, in the application, evaluated but typically not easily quantified as e.g., the impact on standardisation, where the impact is of major relevance but not measurable in % or on politics, where it may be enforced or compensated by unforeseen events.

8.1. Societal Impact

There were 10 societal impacts foreseen for MOTIONAL:

1. Passengers and freight users of railways experiencing more dynamic reaction on forecasted changes in traffic demand
2. More reliable train services due to traffic management operators and systems being able to adapt more quickly and earlier to possible deviations or disruptions
3. Improved monitoring and customer information with respect to early communication of traffic deviations and impact using digital technologies
4. Reduction of the impact of track maintenance activities on train operations allowing to maintain the level of service availability and quality
5. Using last cutting-edge technology to adapt the transport system to globally changing requirements
6. Helping PRM and passengers with special needs
7. Incentivize people in their choice of mobility
8. Enable customer trust through the providing of reliable and reactive transportation services
9. Streamline traveller flows in crowded stations
10. Encourage participation of individuals, mobility businesses and institutions in the digital mobility economy through the federated dataspace

These 10 impacts were already mapped to the Societal KPIs established by the JU. The mapping can be found in (Table 5) with blue fields indicating no impact, orange little to medium impact and red high impact.

Table 5: Mapping of societal Impacts to societal KPIs. No impact (blue), little to medium impact (orange), high impact (red)

Societal Impact	Energy Savings in Transport	GHG Emission Savings in Transport	Congestion Savings in Transport	Rail Affordability	Rail Connectivity	EU Rail Sector Competitiveness	Occupational Safety in Rail	Passenger Safety in Transport	Circular Economy
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									

8.2. Economical Impact

- Enabling ATO and C-DAS technology to achieve the expected gains in network capacity and energy saving by appropriately reflecting the system's behaviour in planned or dynamic timetables and resulting journey profiles controlling the trains;
- Cost savings due to reduction of delay or train cancellations and related penalty payments;
- Increase of revenues for IMs and RUs by allowing very short-term path allocation especially for freight and cross-border relations;
- Unified, scalable system architecture allowing for simple regional TMS applications with low effort as well as more sophisticated solutions for higher traffic densities and complex network topologies;
- Improvement of the company' system efficiency aiming to reduce costs and give better experience to the passengers;
- Breaking silos between mobility modes, public and private mobility providers
- Protection of investments in public transportation services;
- Development of efficient B2B interaction, especially financial flows;
- Reduce the cost of ambiguities in system specifications, of prototyping, testing and validation, shortening time to deployment through end-to-end digitalisation of assets planning, design, engineering, manufacturing, deployment and maintenance process and the use of Digital Twins;
- Contribute to the construction of European Dataspaces as defined by the European Data Strategy to accelerate transition to the European digital economy.

8.3. Environmental Impact

The following environmental impacts are foreseen:

- Reduction of CO2 emissions due to accurate TMS traffic prediction and preventing of dispensable operational stops;
- Reduction of CO2 emissions due to consideration of ATO/C-DAS capabilities in the dynamic timetables and related journey profiles;
- Enable modal shift towards environmental friendly modes by improved services matching demand with regard to frequency, quality, accessibility, technology;
- Promotion of green efficiency and quality mobility services;
- Reducing the waste by introducing seamless validation which aims to eliminate any physical plastic or others type of support.

8.4. Technological Impact

- Upgrade of simulation tool technology for railways;
- Use of innovative technologies such as AI or machine learning and Web based UIs in the area of traffic management;
- Exploit the capacity of innovative communication and positioning technologies such as UWB, 5G;
- Implement cyber-physical system virtualization with Digital Twins modelling and simulation using advanced algorithms and artificial intelligence;
- Contribute to development of European-wide dataspaces and high-performance computing for innovation.

8.5. Scientific Impact

- New methods for more pro-active visualisation and interaction with traffic management system for users and stakeholders;
- New concept by planning and proactive traffic control to always have an updated real time traffic plan for network and major nodes;
- Innovative optimisation algorithms and AI to boost decision making performance and quality in traffic management and planning;
- Today gap between what is theoretically possible to do and what has been implemented in practice. We intend to extend, combine and improve successful techniques, such as mathematical optimization and machine learning equipped with advanced simulation.
- Existing algorithms usually work only on small/medium sized instances and have difficulties to scale to large-scale real-life problems. In MOTIONAL we intend to close part of this gap by exploiting strong mathematical/algorithmic competence of our academic and industrial partners with the field knowledge provided by practitioners.
- New ways of interaction with the environment in stations (hands free, touchless, guidance, ...);
- New simulation methods of traffic, demand and customer behaviour using Digital Twin technology;
- New knowledge on system static and dynamic behaviour (state functions, equations) of multiple interacting components using Digital Twin simulation and data science analysis;
- Knowledge and information infrastructure are built up to guide and help actors to improve their methods.

8.6. Political Impact

- Increased awareness of the work done in the MOTIONAL project at the European and national level (contact with European parliament, MEPs, National agencies) with the aim to maximise the relevance of the proposed regulation and standardisation.
- Increased acceptance of rail operation e.g. in the frame of climate protection measures.

8.7. Regulations & Standardization Impact

- Harmonised functional TMS architecture aligned with the System Pillar and the involved sector organisations;
- Delivering the capability of an interoperable traffic management on a European dimension;
- Contribute to development of existing standards CEN, ERA. to support the development of B2B exchanges;
- Generate formal specifications in the form of digital machine-readable models for regulation and standardisation using digital engineering methods and tooling and Digital Twins.

9. Conclusions

This document provides a comprehensive overview of the metrics and methodology used for the assessment of KPI achievements and impact. It is the base for any additional KPI related documents within MOTIONAL. Our objective is to establish a credible pathway to technical KPIs through performance indicators (PIs) of MOTIONAL. A mapping from Use Cases (WP level) to Demo Cases (WS level), from Demo Cases to PIs, and, ultimately, from PIs to KPIs was established and will be developed further throughout the project.

The assessment of KPIs is done through setting up a baseline. The general baseline is the year 2022 with respect to operational performance indicators, as well as parameters of technology implemented in the field. Technology available on the market, but not applied on operational lines, will not be considered as baseline. In case of lacking sufficient data for 2022, data of later or earlier years will be used depending on their availability and coherency with the KPIs and PIs. There are cases where no baseline is needed, and the KPIs/PIs are measured in absolute values.

We defined three validation methods, each having specific advantages and disadvantages. To validate the progress towards the KPI, we can use Demonstrations, Simulations and Expert Judgement. In this early stage of the EU-Rail Programme we have to use Expert Judgement for many KPIs, as there are no demonstrations for the KPIs planned in MOTIONAL. Technical developments and more holistic demonstrations are expected within the future projects of the programme.

The KPI approach differs from the chosen method for the PIs, where we selected a comparison of current TRL to the target TRL. The PIs of the technical (WS1) and digital enablers (WS2) will be achieved during the MOTIONAL Project, they have a TRL associated with them and will be demonstrated in accordance with the assigned TRL. This method allows full insight in the current status of the PIs, which are planned to increase towards the end of the project.

We defined the metric and methodology for KPIs and PIs, this information provides clear instructions on what kind of data is measured. We explain data types, time frame, order of operations, and potential limitations.

The technical developments within MOTIONAL will impact a variety of fields of our lives. Our project PIs can be mapped quantitatively to the Economic and Societal Impacts, which makes an assessment possible. All remaining impacts can be assessed only qualitatively. The level of complexity of the developments and the numerous interdependencies within the system and the real world make it impossible to calculate the impacts precisely or map certain technical enablers directly to a specific impact. The results of the project can only be evaluated in a holistic approach and taken as estimation.

Nonetheless, we come to the conclusion that the methods and approaches listed in this document are the best way forward and fulfil the objectives of this deliverable. This document will provide the baseline of all future work concerning KPIs within MOTIONAL and also Flagship Area 1.

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11. Annex 1 – Technical and Digital Enablers of FA1-MOTIONAL

#	Technical Enabler	WP	TRL
1	European cross-border scheduling with international train path planning	4/5	6/7
2	Improved capacity allocation using rolling planning and TTR	4/5	6/7
3	Decision support for short term planning	6/7	5/6
4	Train path and schedule optimisation methods and strategies for capacity efficiency, punctuality and energy saving for different parts of the network and different traffic situations (level of punctuality)	6/7	5/6
5	Improved rail traffic simulation models for selected Use Cases to forecast punctuality in the network (e.g., simulating proportion primary and secondary delays, simulations drivers vs. ATO over ETCS).	6/7	6/7
6	Integration of planning systems and TMS with a) yard capacity planning and b) station capacity planning	4/5/6/7	5/6
7	New planning and operational processes using feedback loops from ERTMS ATO and C-DAS	6/7	5/6
8	Real-time connection of rail networks as managed by TMSs and involved actors	11/12	6/7
9	Modelling and decision support for cross-border traffic management	11/12	5/6
10	Integration of TMS with a) yard management system and processes; b) station management system and processes; c) energy management (Electric Traction System); d) real-time crew / rolling stock dispatching	11/12	6/7
11	HMI for TMS based on User Experience (UX) Design and user input	13/14	8
12	Real-time convergence between planning & feedback loop from operations	15/16	4/5
13	Cooperative planning multi-actors within rail	13/14	4/5
14	Integration of incident management and customer information, with IM and RU interaction and Decision Support for Disruption management	13/14	4/5
15	TMS speed regulation of trains, precise routes and target times for ATO and dynamic timetables	15/16	4/5
16	Automation of very short-term train control decisions	17/18	5
17	Real-time conflict detection & resolution for main line and optimisation	17/18	4/5
18	Improve Rail integration using B2B Intermodal Services	20/21	6/7
19	Develop Standardised Interfaces	20/21	7/8
20	Travel Assistance across modes (esp. PRM)	22/23	4/5
21	Hands-free Solutions & Smart Information	22/23	7/8
22	General approach to platform-based guidance	22/23	4/5

23	Short Term Demand Forecast Calculation	24/25	6/7
24	Long Term Demand Forecast Calculation	24/25	5
25	Integration of Demand Forecast into Digital Twin	24/25	5
26	Optimise rail capacity to better match the demand	24/25	5
27	Manage/ Inform Disruptions across modes	24/25	6/7
28	development of federated data space for data sharing and communications across all Destinations	31	6
29	development of machine-readable semantic and syntactic abstract data model for all Destinations	30	6
30	development of methodology supported by toolbox for digital assets engineering	27	6
31	provision of Digital Twin development and run-time simulation environment for creation of modular, interoperable, composable Digital Twins	28/29	5

12. Annex 2 – Mapping of KPIs and PIs

The PIs of MOTIONAL are mapped to the existing KPIs documented in the MAWP. Furthermore, the table contains the baseline and specific contribution of the project, WP, and Enablers to the PIs for WS1.1, WS1.2, WS1.3 and WS2. Additionally, Demonstration Case IDs are listed for WS1.1 and WS1.2. Use Case IDs are listed for WS1.3. The following columns can be found:

- WS: Workstream
- No of MAWP KPIs: Number of KPI within MAWP
- KPIs in MAWP for 2031 (GA [27] Table 17): Listed KPIs within MAWP
- Specific contribution of FP1-MOTIONAL (GA [27] Table 17): Contribution from project to KPIs
- No of Project PIs: Number of Performance Indicators (PIs) of the project
- Performance Indicators for MOTIONAL (GA [27] Table 11/12): Listed PIs within GA
- Baseline (GA [27] Table 11,12): Defined Baseline of Q2/2022
- Specific contribution of the Project (GA [27] Table 11,12): Contribution from project to PIs
- WP: Involved Work Packages
- Enabler: Involved Enabler
- Demo Number WS1.1 & WS1.2: List numbers of Demo Cases that relate to the PI
- Use Case Number WS1.3: List numbers of Use Cases that relate to the PI

WS	No if KPI in project	No of MAWP KPIs	KPIs in MAWP for 2031 (GA Table 17)	Specific contribution of FP1-MOTIONAL (GA Table 17)	No of Project PIs	Performance Indicators for MOTIONAL (GA Table 11/12)	Baseline (GA Table 11,12)	Specific contribution of the Project (GA Table 11,12)	WP	Enabler	Demo Case ID (WS1.1-WS1.2)/ Use Case ID (WS1.3)
1.1	KPI1.1	KPI1	Increased number of possible trains on a given infrastructure on a reference day using improved processes and methods: Baseline 2022, expected increase 5% to 20%, depending on the line or area Reduction of answering time between the short-term request of a cross-border train path and the answer with an adequate offer: Down to 5 minutes	Improved planning systems by integrated support modules for new rolling processes, for European Infrastructure Managers in cooperation with Rail Net Europe. Improved national planning and cross border planning Cooperation between partners and experts (WP4/5, WP6/7, WP8/9).	PI1	Number of solutions developed: 3 Number of solutions implemented: 1	Baseline: Number of integrated solutions implemented today is none (0). Number of integrated cross-border dispatching solution is none (0). Existing research Sweden demonstrators Railway CDM sharing operational data and timestamps. S2R FR8Rail III YCS demonstrator co-operative decisionmaking concept simulated with operational data off-line.	Within WP4/5 and WP11/WP12 the focus is on the development, implementation and demonstrations for cross boarder decision solutions, as well as better integrated systems and modules within Europe.	4, 5, 11, 12	1, 2, 8, 9, 10	WS1.1: 1-5 WS1.2: 1-9
					PI2	Number of optimised timetable solutions: 3 Number of solutions implemented: 1	Baseline: Number of integrated solutions implemented today is none (0) Some solutions for optimised timetable implemented at local basis	Within WP4/WP5, WP6/WP7 and WP8/WP9 the focus is on the development and implementation of timetable solutions using optimisation and simulation for planning. Optimisation as an integrated part of decision support.	4, 5, 6, 7, 8, 9	3, 4, 5, 6, 7	WS1.1: 1-9
					PI4	Number of integrated information interfaces that will contribute to a harmonised cross-border traffic management supported by the future European TMS: 2	Baseline: Number of integrated information interfaces for Cross border traffic, none (0)	Within WP 4/5 and WP11/WP12 the focus is on the development, implementation and demonstrations for cross boarder decision solutions, as well as better integrated systems and modules within Europe. Seven (7) demonstrators with TRL 5 and two (2) demonstrators with TRL5/6 will be developed.	4, 5, 11, 12	1, 2, 8, 9, 10	WS1.1: 1-5 WS1.2: 1-9
1.1	KPI1.3	KPI2	Improved robustness of timetables and hence, reduced impact of disturbances and disruptions: Baseline 2022, expected decrease 5% to 15% of delay minutes in a reference week depending on the line or area	Developed methods and tools that enable IM/RUs to go from reactive to proactive planning and control (WP4/5, WP6/7, WP8/9).	PI3	Number of successful feedback loops solutions put in place between operations and planning: 2 Number of developed methods for TMS – C-DAS/ATO: 2	Baseline: Different solutions and levels for feedbacks loops implemented today	Within WP8/WP9 the focus is on the development and implementation of feedback loops solutions that can be used in operation and planning as well as TMS-C-DAS/ATO.	8, 9	5, 7	WS1.1: 1-10
1.2	KPI2.1	KPI3	Prediction Quality as the basis for decision quality in Traffic Management: For a representative set of 100 trains running in a 2h interval ahead of actual time, less than 5 percent of the predicted timing shall not deviate from the actual more than 5 minutes. Note: Train cancellations not considered	Highly accurate train prediction calculation in TMS will be developed considering integrated asset, energy, rolling stock or crew restrictions (WP11/12) and automated resolution of track occupancy conflicts (WP15/16 and WP17/18).	PI5	Number of multi-actor planning and decision support system solutions for incidents and disruptions with human-in-the-loop recognition in place: 2	Baseline: Different solutions and levels for incidents and disruptions management are implemented today	Within WP13/WP14 the focus is on the development, implementation and demonstrations for incident and deviation management with human in the loop recognition and multi actors solutions.	13, 14	11, 13, 14	WS1.2: 10, 11
1.2	KPI2.2	KPI4	Prediction performance as the basis for in-time decision making in Traffic Management: less than 120 seconds in a typical set of 100 trains running in a 2h interval ahead of actual time. Note: Prediction shall consider dynamic infrastructure constraints (e.g., TSR, track blockages), implemented train control decisions and automated conflict resolution	The train prediction calculation developed for TMS considering integrated asset, energy, rolling stock or crew restrictions (WP11/12) and automated resolution of track occupancy conflicts (WP15/16 and WP17/18) will be based on modern architecture and high-performance algorithms.	PI7	Computing time to produce a feasible (= conflict-free) plan i.e., a route and a schedule for each train, with a set of 100 trains running in a 2h interval ahead of actual time, running at most 60 seconds.	Baseline: Different solutions and levels for solving timetable conflicts are implemented today but mostly with very limited scope and reaction times > 1min; none (0) are used in production.	Within WP17/WP18 the focus is on the development and implementation of TMS modules for timetable conflict resolutions with automated decision support.	17, 18	16, 17	WS1.2: 16-25
1.2	KPI2.3	KPI5	ATO Journey Profile / Segment Profile provision cycle time down to 30 secs	Precise ATO Journey Profiles and Segment Profiles are generated and submitted to ATO-TS based on developments in WP15/16 and WP11/12 using up-to-date technology and architecture.	PI6	Number of TMS - ATO/C-DAS modules tested and assured individually ready to build up complexity step-by-step: 3	Baseline: TMS-side is less developed. TMS-C-DAS/ATO is under a current evolution and transition. A few ATO-lines in operation	Within WP8/WP9 and WP15/16 the focus is on the development and implementation to gradually build up TMS - ATO/C-DAS modules with increased complexity.	8, 9, 15, 16	5, 7, 12, 15	WS1.1: 1-12 WS1.2: 12-15

WS	No if KPI in project	No of MAWP KPIs	KPIs in MAWP for 2031 (GA Table 17)	Specific contribution of FP1-MOTIONAL (GA Table 17)	No of Project PIs	Performance Indicators for MOTIONAL (GA Table 11/12)	Baseline (GA Table 11,12)	Specific contribution of the Project (GA Table 11,12)	WP	Enabler	Demo Case ID (WS1.1-WS1.2)/ Use Case ID (WS1.3)
1.3	KPI3.1	KPI6	Demand forecast for improved service planning: Achieve 80% precision in the forecast at 1 hour Achieve 65% precision in the average forecast 1 week in advance	Functionalities and a profiling information system for real-time service offers matching the current demand at multimodal hubs will be developed. Parameters to be considered: occupancy forecast, short-term demand, long-term demand, disruptions, passenger flows (WP24/25).	PI10	Calculation of the short-term demand prediction is feasible There is a distribution of predicted demand by hour There is detection of deviations not contemplated in baseline	Baseline: There is no available distribution per hours for a predicted demand Currently there is no mechanism for the detection of deviations	Supporting operators with detailed and reliable real-time data and the development of a short-term profiling information system (WP24/WP25) will facilitate to reach the listed Performance Indicators.	24, 25	23, 24, 25, 26, 27	WS1.3: UC-FP1-WP19-31 - UC-FP1-WP19-54
1.3	KPI3.2	KPI7	Improved matching between demand and supply: Achieve 75% reaching passengers' planned travel time	More accurate short and long-term demand calculations, optimised rail capacity, improved disruption management (WP24/25) will help operators to make better predictions of travel time, but also to provide alternative travel routes and transportation modes if needed. The developed MaaS platforms for B2B intermodal services as well as the work on standardised interfaces will support this effort (WP20/21). Furthermore, travel assistance across modes (esp. PRM), hands-free experience during transfer between mobility modes and platform-based guidance help to facilitate a smooth flow of passengers (WP22/23).	PI8	Number of B2B services put in place >3	Baseline: Only rudimentary approaches are present for B2B services	Within WP20/WP21 the focus is on the development and implementation of B2B services regarding e.g., booking, financial services, data exchange.	20, 21	18	WS1.3: UC-FP1-WP19-01 - UC-FP1-WP19-11
					PI9	Impact on passenger flow and traveller satisfaction. Based on the demos survey: Impact on passenger flow > 25% Customer satisfaction when using the proposed inclusive services > 75%	Baseline: related to demos context: existing solutions available at the station, digital assistance and automatic gates.	Services and solutions that improve travel quality especially at connection time in intermodal hubs are the key objectives of WP22/WP23. Topics cover: PRM support, hands-free experience, smart solutions for improved passenger flow and guidance.	22, 23	20, 21, 22	WS1.3: UC-FP1-WP19-12 - UC-FP1-WP19-30
					PI10	Calculation of the short-term demand prediction is feasible There is a distribution of predicted demand by hour There is detection of deviations not contemplated in baseline	Baseline: There is no available distribution per hours for a predicted demand Currently there is no mechanism for the detection of deviations	Supporting operators with detailed and reliable real-time data and the development of a short-term profiling information system (WP24/WP25) will facilitate to reach the listed Performance Indicators.	24, 25	23, 24, 25, 26, 27	WS1.3: UC-FP1-WP19-31 - UC-FP1-WP19-54

WS	No if KPI in project	No of MAWP KPIs	KPIs in MAWP for 2031 (GA Table 17)	Specific contribution of FP1-MOTIONAL (GA Table 17)	No of Project PIs	Performance Indicators for MOTIONAL (GA Table 11/12)	Baseline (GA Table 11,12)	Specific contribution of the Project (GA Table 11,12)	WP	Enabler
2	KPI4.1	KPI8	Number of infrastructure inspections that can be conducted in laboratory without requiring field inspection: % increase in lab	Digital Assets Engineering methodology and toolbox developed by WP27, compartmented by the Digital Twin support, development and run-time environment developed in WP28/29, will provide all Destinations with common tooling for the creation of modular, interoperable, composable virtual replicas of cyber-physical assets, allowing for digital prediction of their future state and for their validation and certification through simulations. Simulations and prediction algorithms will use historical and actual data collected and shared through the federated data space data sharing and communications infrastructure developed by WP31. As a result, most assets (rolling stock, infrastructure) tests and validations will be conducted using formal methods in the laboratory, reducing the need for physical inspections.	PI11	Number of implemented IDS connectors; mean of Verification: registered number of IDS connectors	none	Based on requirements for access to data sources generated by WP2 for FP1-MOTIONAL project's demonstrators, and by WP26 for other Destinations, WP31 implement 4 to 9 IDS Connectors for secure and reliable data sharing and communications.	26, 31	28
2	KPI4.2	KPI9	Number of rolling stock inspections that can be conducted in laboratory without requiring field inspection: % increase in lab		PI12	Number of users of IDS broker services; mean of Verification: registered number of users	none	The IDS broker developed by WP31 is the extensible central element adding participants to the data space federation through registration of their Connectors. The 4 to 9 Connectors created to meet Objective 11 will be registered in the IDS broker.	31	28
2	KPI4.3	KPI10	Number of virtual certification tasks that can be conducted in a laboratory: % increase in lab		PI16	Number of users of the digital assets engineer toolbox	Baseline: 30 (EULYNX, RCA projects)	The Digital Assets Engineer toolbox developed by WP 27 will expand its user base by a minimum of 50%, making it available also to System Pillar engineers.	27	30
2	KPI4.4	KPI11	Number of predicted future behaviours thanks to the Digital Twin use: % increase in predictions							
2	KPI4.5	KPI12	Number of times the same data type is managed in isolated manner in a process using an independent system: No. uf use	The Common Domain Ontology / Conceptual Data Model (CDM) developed by WP30 will provide a formally validated machine-readable abstract semantic and syntactic description of the data shared through the federated data space developed by WP31. The CDM will incorporate the ability to generate specific concrete project-specific data structures automatically, guaranteeing their conformance to a common model. As a result, data types will no longer be managed in isolation in specific projects and systems and, generated from the common abstract model they will be 'harmonised'.	PI14	Number of data models in the Common Domain Ontology/Conceptual Data Model	6	WP30 will develop extensions and evolve the current Common Domain Ontology / Conceptual Data Model adding 1 to 4 models from requirements generated by WP2 for FP1-MOTIONAL projects and collected by WP26 for other Destinations.	26, 30	29
2	KPI4.6	KPI13	Number or share of data entities that have been homogenized: No. of use		PI15	Number of users of the machine-readable, platform independent, abstract Rail System common domain ontology / conceptual data model	Baseline: 20 (OPTIMA project, LINX4RAIL demonstration)	The extended Common Domain Ontology / Conceptual Data Model repository developed by WP30 will expand its user base by a minimum of 30%, with further increase depending on requirements generated by WP2 for FP1-MOTIONAL projects and collected by WP26 for other Destinations.	26, 30	29
2	KPI4.7	KPI14.1	% of coverage physical asset with related digital twins (completeness) % increase in Coverage	The Digital Twin support, development and run-time environment developed by WP28/29 will leverage the standard Functional Mock-Up Interface to ensure Digital Twins interoperability and conformance to common specifications of all Digital Twins created in all Destinations. In addition, the CDM conceptual domain ontology / conceptual data model (WP30), and the common federate data space sharing and communications infrastructure (WP31) will also be designed to guarantee commonality of tooling and methods across all Destinations. As a result, the opportunities for creating consistencies across Digital Twins will be eliminated by design.	PI13	Number of users of IDS AppStore; mean of Verification: registered number of users	none	The IDS AppStore developed by WP31 will store compiled Digital Twin as composable and interoperable functional mock-up units. The IDS Appstore is used by Digital Twin users through the IDS Connectors. The 4 to 9 Connectors created to meet Objective 11 will be registered users of the IDS AppStore.	28, 29, 31	28,31
2	KPI4.8	KPI14.2	% of errors present in the Digital Twins list (inconsistency): % reduction against 2022 baseline		PI17	Number of Digital Twins supported by the Digital Twin support, development and run-time environment	none	The Digital Twin support, development and run-time environment developed by WP28/WP29 will be based on the functional mock-up interface standard to facilitate the creation of composite higher order Digital Twins for railway applications and will validate the approach with at least 2 Digital Twins.	28, 29	31
2	KPI4.9	KPI15	Data Security – Role based security of data in DT environment measured by passing of white hack test: Increase in no. of survived tests	The federated data space for data sharing and communications will be developed in conformance to the International Data Space Association's (IDSA) Rule Book and Reference Architecture Model. It will be certified for compliance by the IDSA Certification authority and built using open source IDSA-compliant and maintained 'building blocks' which contain built-in cybersecurity, reliability, performance and scalability provisions as essential architectural features of the European data spaces included by design in the reference architecture model. By complying with a robust design and implementation explicitly conceived to support large scale and secure data spaces, the federated data space will be able to meet the Rail Systems requirements for cyber-security, interoperability, scalability and performance better than it could with a home-grown solution.	PI18	Related to Dataspace components PIs: Connector, Broker, AppStore	none	The federated dataspace is used to share data for Digital Twins. SInce the dataspace it is built from standard 'building blocks' compliant with the Trust and Security framework of the GAIA-X Association for European Dataspaces, it incorporates strict built-in cybersecurity features specified and certified by the GAIA-X association specifically for distributed, data soverigny-preserving data sharing and communications.	31	28
2	KPI4.10	KPI16	Time to respond and resolve a vulnerability: Reduced time		PI19	Related to Dataspace components PIs: Connector, Broker, AppStore	none	Standard dataspace components implement built-in cybersecurity features including detection of breach attempts that help early identification of vulnerabilities. Being standardized, the components are supported by a community of experts that provide support for dataspace, including for closing potential vulnerabilities, shortening the time to resolution	31	28
2	KPI4.11	KPI17	Time to complete a data transfer task from the Edge to the Cloud: Reduced time		PI20	Related to Dataspace components PIs: Connector, Broker, AppStore	none	Standard dataspace components implement 'out-of-the-box' data transfer protocols via Connectors for already optimized multiple exchange patterns, e.g. pull, push, batch, etc, using adaptive algorithms, such as compression, parallelization, and others.	31	28